Strength Characteristics of M20 Grade Concrete Incorporating Eggshell Powder, Silica Fume, and GGBS as Cement Replacements

Abhishek Bagewadi[1], Dhananjay B. H[2], Arsh S. Khan[3], Sapnil V. Desai[4], Vijaylaxmi B. V[5],

[1,2,3,4] Undergraduate Student, Dept. of Civil Engineering, KLS VDIT, Haliyal, Karnataka, India
[5] Assistant Professor, Dept. of Civil Engineering, KLS VDIT, Haliyal, Karnataka, India

---***---

Abstract - The modern construction requires very large amounts of raw materials, and the rising cost of cement has led researchers to look for sustainable alternatives. Cement production uses a lot of energy and causes environmental pollution. Therefore, eco-friendly supplementary materials are needed. Eggshell Powder (ESP), Silica Fume (SF), and Ground Granulated Blast Furnace Slag (GGBS) are promising options because of their cementitious and pozzolanic properties. ESP is a calcium-rich agricultural waste, while SF and GGBS are industrial by-products. These materials can improve concrete strength, durability, and sustainability while reducing cement use and environmental impact. This study examines the mechanical performance of M20 grade concrete with partial cement replacement using ESP, SF, and GGBS at 0%, 10%, 20%, and 30%. We were using Ordinary Portland Cement (OPC) 43 grade. Concrete cubes and cylinders were cast and tested to find the best replacement level. The compressive and split tensile strength were determined after 7 and 28 days of curing. The aim is to find the most effective combination of ESP, SF, and GGBS that can replace part of cement without reducing concrete durability and strength. The results provided useful insights for using agricultural and industrial waste in sustainable construction.

***Key Words*:** Sustainable Construction, Partial Cement Replacement, Eggshell Powder (ESP), Silica Fume (SF), Ground Granulated Blast Furnace Slag (GGBS), M20 Grade Concrete, Compressive Strength, Waste Utilization.

1.INTRODUCTION

Concrete remains one of the most commonly used construction materials because it offers high compressive strength, long-term durability, and is relatively economical. Despite these advantages, the production of cement the main binding ingredient in concrete contributes nearly 7% of global CO_2 emissions, creating significant environmental challenges. To address this issue, recent research has focused on the use of supplementary cementitious materials (SCMs). These materials can partially replace cement and help lower the carbon footprint of concrete while maintaining its essential engineering properties.

This study focuses on three promising SCMs: ESP, SF, and GGBS.ESP is been a agricultural waste rich in calcium carbonate, similar to a limestone used in cement. SF is a byproduct of the silicon industry known for improving strength and durability. GGBS is a steel industry byproduct that enhances long-term strength and resistance to chemical attacks. While these materials have been studied individually, there is limited research on their combined use in M20 grade concrete, which is commonly used in residential construction. Most previous studies have been focused on higher grades and single-material replacements.

This work intends to fill that gap by studying the combining of ESP, SF, and GGBS is being partial substitutes for cement in M20 concrete. Various mixes will be tested for compressive strength, split tensile strength, workability, and water absorption to identify an optimal, eco-friendly, and durable mix.

2.LITERATURE REVIEW

2.1. Literature survey on Egg Shell Powder (ESP)

[1] In this paper Eggshell powder, which contains high calcium carbonate, can be used as a replacement of cement to improve concrete performance. Studies show it accelerates hydration, enhances early strength, reduces permeability, and refines the microstructure. Replacing up to an 20% of a cement with eggshell powder significantly increases compressive strength. An ANN model with $R^2 = 0.96$ effectively predicts strength, supporting this sustainable approach for reducing waste, conserving resources, and improving concrete quality.

[2] In this study the literature traces the use of a Supplementary Cementitious Materials (SCMs) from ancient Greek and Roman construction to modern concrete. Today, industrial and natural by-products like Pozzo Crete, saw, rice husk ash, eggshell powder, and bagasse ash can replace part of Portland cement, lower cost and improving sustainability. The review highlights eggshell powder as a promising SCM that supports waste management while enhancing both fresh and hardened concrete properties.

[3] In this research the review highlights that the of (ESP) in concrete, noting that India generates about 1.9 million tons of eggshell waste yearly, creating environmental issues. Rich in calcium and similar to limestone, ESP can partially replace cement or fine aggregate. Its use reduces CO_2 emissions, saves energy, and supports waste management. Studies show ESP can improve workability, strength, durability, and sulfate resistance, making it a sustainable construction material.

2.2. Literature survey on Silica Fumes (SF)

[4] In this experiment the research examines the combined use of silica fume and steel fiber to enhance concrete performance. Silica fume replaced cement at 9%, 10%, and 11%, while 0.5% steel fiber was added. Silica fume improved cohesiveness and flow in fresh concrete and increased compressive strength at all ages. Steel fiber enhanced toughness and durability. The study concludes that this combination produces high-performance concrete suitable for sustainable, resilient construction.

[5] In this study the research analyses the partial substitution of cement with silica fume (0–20%) in M20 concrete. Specimens were tested for compressive, split tensile, and flexural strength at 7 and 28 days, and durability was evaluated through acid-attack weight loss. Results show that silica fume enhances both strength and durability while reducing cement use. The study

confirms silica fume as an effective supplementary material that supports resource conservation and sustainable construction.

2.3. Literature survey on GGBS

[6] In this experimental explores using (GGBS), an industrial by-product, as a partial substitute for cement in M30 concrete to reduce carbon footprint, cost, and cracking. Concrete cubes with 0–30% GGBS were tested for a compressive strength at 7, 14, and 28 days. Results show GGBS improves workability, durability, and long-term strength, with an optimum replacement identified. The study highlights GGBS as a sustainable, high-performance alternative for construction.

[7] The study investigates the utilization of GGBS as a partial substitute for cement in concrete the authors assessed strength, durability, workability, and sustainability. Concrete mixes with varying GGBS levels showed that 20% replacement achieved the highest compressive strength, with higher amounts reducing strength. The results highlight GGBS as an eco-friendly material that reduces cement use while maintaining performance, supporting sustainable construction practices.

2.4. Literature survey on GGBS

[8] In this the author research investigates using ESP and SF as partial cement replacements in M25 concrete to enhance sustainability. Cement was replaced with 2.5–10% of ESP and silica fume, and concrete was tested for workability, compressive strength, and split tensile strength. Results show that these waste by-products reduce cement consumption, lower CO_2 emissions, and conserve resources, while improving mechanical performance, demonstrating their potential for environmentally responsible and high-performance construction.

[9] In this paper studied the use of silica fume (5%–15%) and GGBS (10%–40%) as partial cement replacements in M30 concrete to enhance performance and sustainability. Cubes and cylinders were evaluated for compressive and split tensile strength at 7 and 28 days. Results showed that incorporating SF and GGBS improves strength and durability while reducing cement consumption, supporting eco-friendly construction and demonstrating the feasibility of using industrial by-products without compromising concrete performance.

3.RESEARCH GAP

Over the past decade, many studies have been conducted on the alternative materials in concrete to decrease cement usage and promote sustainability. Materials like ESP, SF, and GGBS have been tested individually, and they have shown tremendous results in improving the strength and durability of concrete. These materials not only help in managing waste but also enhance the performance of concrete when used in appropriate proportions. However, the majority of these studies focus on individual materials or higher-grade concretes such as M25, M30, or M40. There is very limited research on the combined effect of ESP, SF, and GGBS in M20 grade concrete, which is commonly used in residential and small-scale building projects. Most of the majority of existing research explores either the mechanical or the durability aspects of a single replacement material, and few studies consider a mix containing all three components. Further, the optimal percentage of these combined materials that yields the best balance between strength, durability, and workability has not been clearly examined in existing research. Additionally, while individual replacements have been shown to affect concrete properties like workability, water absorption, and setting time, there is little information about how these characteristics alter when all three materials ESP, SF and GGBS are used together. It is also unclear how these combinations perform in terms of long-term durability and practical usage for M20 concrete applications.

This work aims to fill this research gap by studying the combined influence of ESP, SF and GGBS as partial replacements of cement in M20 grade concrete. It will focus on evaluating the mechanical and durability qualities of concrete utilizing varied mix amounts and curing ages. The objective is to determine an optimum blend that not only improves performance but also supports sustainable construction.

4.OBJECTIVE OF STUDY

This study intends to assess the influence of partially substituting ESP, SF and GGBS in M20 grade concrete. The major purpose is to examine how these supplemental cementitious elements affect the compressive, split tensile strength and workability of concrete while minimizing the overall carbon footprint by lowering the reliance on conventional cement. The research focusses on establishing the ideal combined replacement levels at 10%,20%, and 30% and testing their performance through 7-day and 28-day compressive strength tests. research aims to encourage sustainable construction methods by minimizing cement use and using eco-friendly waste materials without compromising strength or durability.

5.MATERIAL USED FOR EXPERIMENTS

Eggshell is a poultry industry by-product that is generated in huge quantities and often disposed of as waste, creating environmental problems. Eggshell primarily consists of calcium carbonate ($CaCO_3$, about 90–95%), along with small amounts of magnesium, phosphorus, and organic matter. Due to its high lime content, finely ground eggshell can act as a cementitious or pozzolanic material when partially replacing Portland cement in concrete.

Table -5.1: Egg shell powder chemical composition

Material	Composition
Calcium Carbonate	94% - 98%
Magnesium	1%
Phosphate	1%
Sodium, Iron, Zinc	Very small

Silica fume, also known as micro-silica, is a by-product obtained throughout the production process of silicon metal or ferrosilicon alloys in electric arc furnaces. When quartz (SiO_2) is reduced with coal or coke at about 2000°C, extremely fine, amorphous silica particles are released as vapor, which condense to form silica fume. It consists of ultra-fine, spherical particles (less than 1 µm in diameter) that are highly pozzolanic in nature. the silica fume used was procured from CETEX Microns Ltd.as per the specifications provided by the company

Table -5.2: Silica Fume chemical composition

Material	Composition
Silica (SiO2)	85% min
Aluminum Oxide	1.12% max
Iron Oxide	0.18% max
Sodium Oxide	0.5 - 1.25%

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 09 Issue: 12 | Dec - 2025 SJIF Rating: 8.586 ISSN: 2582-3930

Appearance	Very fine powder
Color	Dark Grey
Odor	Odorless
Mean particle size	25 microns

GGBS is an industrial by-product obtained during the manufacture of pig iron in a blast furnace. When molten iron ore, coke, and limestone are processed in a blast furnace, the impurities form a molten slag. This slag, when rapidly cooled with water, forms a glassy granulated material, which, upon drying and grinding to a fine powder, is called GGBS. GGBS is a highly cementitious material with pozzolanic and latent hydraulic properties. Due to its benefits in strengthening concrete and supporting sustainability, it is often used to partially replace cement. The GGBS used was obtained from Suyog Elements India Pvt. Ltd. (SEIPL).

Table -5.3: GGBS chemical composition

Material	Composition
Silica (SiO2)	34.45%
Alumina (Al2O3)	13.95%
Iron Oxide (Fe2O3)	0.90%
Sulphur Trioxide (SO3)	0.26%
Magnesium Oxide (MgO)	6.03%
Appearance	Off-white

Fig -5.1: SF, GGBS and ESP

6.TEST DATA FROM MATERIALS

Testing is done for all the required materials we need for the making of concrete cubes and cylinders.

1. Cement used: OPC 43 Grade
2. Specific gravity of cement: 3.14
3. Specific gravity of
   a) fine aggregate:2.46
   b) Coarse aggregate:2.52
4. Water absorption of
   a) fine aggregate: 0.9%
   b) Coarse aggregate:0.50%
5. Fineness of cement :2.33%
6. Fine aggregate: Zone 2

7.MIX DESIGN

The mix design for this concrete is as per the test data of material is done utilising IS code book 10262-2019.

Table -7.1: Promotion for design 1 Kg/m³

Cement	Water	CA	FA
358.473	191.58	1043.26	651.122

7.1. Casting and curing of specimens

In order to cast the specimens, a homogeneous concrete mixture comprising cement, fine aggregate, coarse aggregate, ESP, SF, GGBS, and water was prepared. This mixture was then put into cube and cylinder moulds in three layers, each of which was compacted with 25 tamping strokes to eliminate air spaces and guarantee correct consolidation. The moulds were left undisturbed for a full day after the top surface was levelled before being demoulded. After demoulding, all specimens were moved to a curing tank with clean water kept at 27 ± 2°C in accordance with IS 9013 (1978). They were cured for 7 and 28 days to generate the necessary strength before testing.

Table -7.1: Mix proportion for cub in Kg

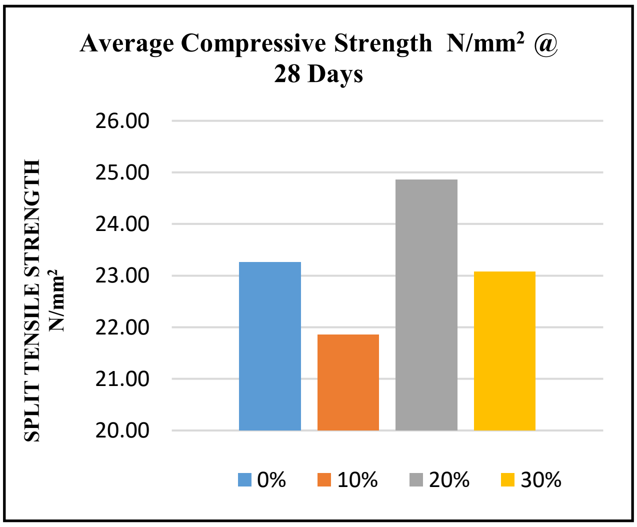
SI NO	Cement Replacement (%)	Cement	Water	CA	FA	(ESP + SF + GGBS) Replacement
1	0% (Control mix)	1.86	0.996	5.42	3.38	0
2	10% (ESP + SF + GGBS)	1.674	0.996	5.42	3.38	(.062+.062+.062)
3	20% (ESP + SF + GGBS)	1.488	0.996	5.42	3.38	(.124+.124+.124)
4	30% (ESP + SF + GGBS)	1.302	0.996	5.42	3.38	(.186+.186+.186)

Table -7.2: Mix proportion for cylinder in Kg

SI NO	Cement Replacement (%)	Cement	Water	CA	FA	(ESP + SF + GGBS) Replacement
1	0% (Control mix)	2.927	1.564	8.517	5.316	0
2	10% (ESP + SF + GGBS)	2.634	1.564	8.517	5.316	(.098+.098+.098)
3	20% (ESP + SF + GGBS)	2.342	1.564	8.517	5.316	(.195+.195+.195)
4	30% (ESP + SF + GGBS)	2.049	1.564	8.517	5.316	(.293+.293+.293)

8.EXPERIMENTAL TEST ON CONCRETE

This is the final test we have done on concrete cubes & cylinders has for fresh concrete we have conducted the slump test and for our project final test we have conducted the



compression & split tensile test for both 7 days and 28 days cubes all the values are taken has average of 3 specimens of every percentage varying

Table -8.1: Slump test (IS 1199 (Part 2) 2018)

Cement Replacement (%)	Slump Value (mm)
0% (Control mix)	102
10% (ESP + SF + GGBS)	79
20% (ESP + SF + GGBS)	73
30% (ESP + SF + GGBS)	62

Table -8.2: Compressive strength test RESULT (IS 516 Part 1)

Percentage% (ESP, SF, GGBS) replacement	Compressive Strength N/mm^2 @ 7Days			Average Compressive Strength N/mm^2 7 Days
	Specimen 1	Specimen 2	Specimen 3	
0%	13.50	14.04	14.61	14.05
10%	13.45	13.82	14.50	13.92
20%	16.83	15.97	15.88	16.23
30%	11.89	13.10	12.19	12.39

Percentage% (ESP, SF, GGBS) replacement	Compressive Strength N/mm2 @ 28 Days			Average Compressive Strength N/mm2 28 Days
	Specimen 1	Specimen 2	Specimen 3	
0%	22.41	23.34	24.04	23.26
10%	23.16	19.64	22.76	21.85
20%	24.98	25.29	24.31	24.86
30%	23.51	21.47	24.27	23.08

Fig -8.1: Average Compressive Strength test for 7 and 28 Days

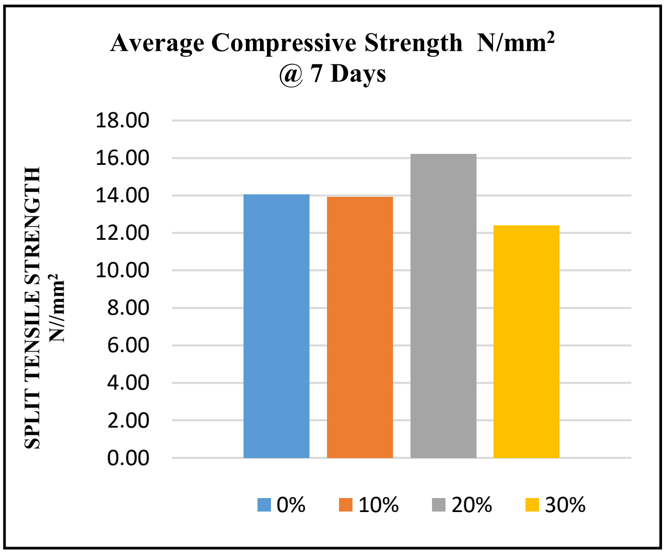
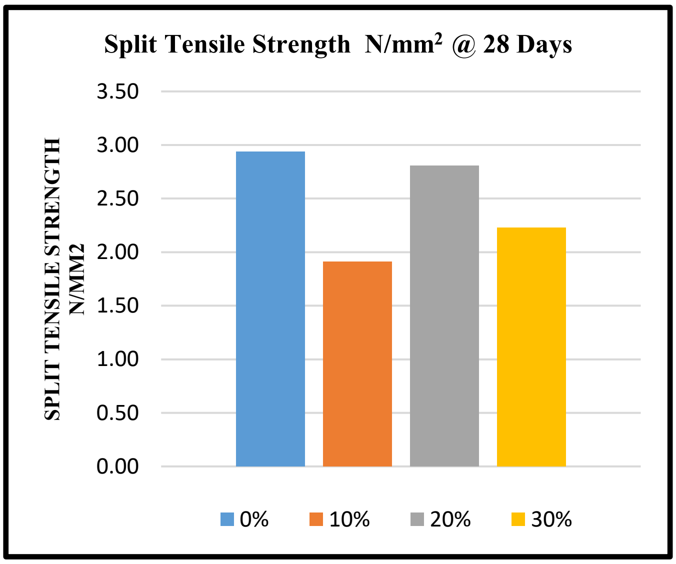
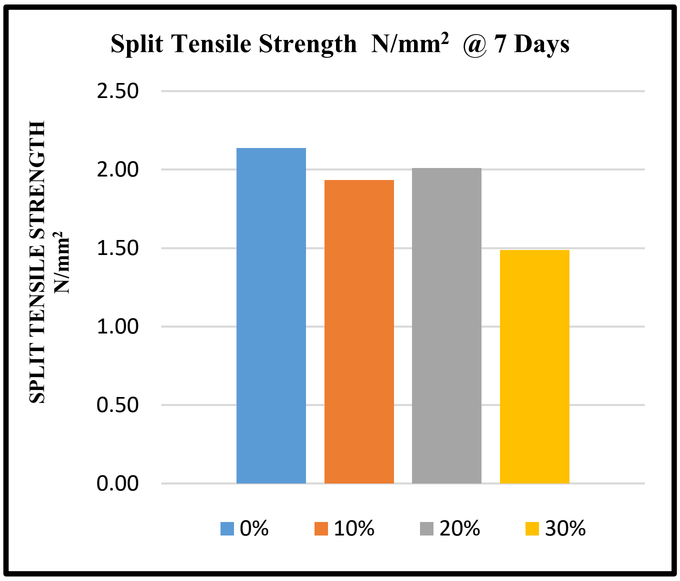


Table -8.3: Split tensile test of cylinders (IS 5816 – 1999)

Percentage% (ESP, SF, GGBS) replacement	Split tensile strength N/mm^2 @ 7days		Average Split tensile strength N/mm^2 @ 7 Days
	Specimen 1	Specimen 2	
0%	2.15	2.12	2.14
10%	2.02	1.84	1.93
20%	2.12	1.90	2.01
30%	1.41	1.56	1.49
Percentage% (ESP, SF, GGBS) replacement	Split tensile strength N/mm^2 @ 28days		Average Split tensile strength N/mm^2 @ 28 Days
	Specimen 1	Specimen 2	
0%	2.97	2.90	2.94
10%	1.98	1.84	1.91
20%	3.00	2.62	2.81
30%	2.26	2.19	2.23

Fig -8.2: Average Split Tensile Strength test for 7 and 28 Days





9.CONCLUSION

This study assessed that combined use of ESP, SF and GGBS as partial replacements for cement in M20 grade concrete. The experimental findings demonstrated that the strength and workability of concrete were greatly impacted by the addition of these additional cementitious elements. Among the studied mixes, the 20% replacement level displayed the highest compressive and split tensile strength, indicating improved microstructure and higher pozzolanic activity. While the 30% mix lost strength as a result of an excessive reduction in cement content, the 10% replacement mix likewise performed well and was comparable to regular concrete. Workability declined with increased replacement levels due of the finer particles and higher water demand of ESP and SF. Overall, the study confirmed that the combined usage of ESP, SF, and GGBS can minimise cement use, lower the carbon footprint, and improve mechanical qualities when utilised within the optimum range.

REFERENCES

1. Sagar Paruthi, G. Naveen, and R. Sathish Kumar, "Review on partial replacement of cement by eggshell powder in concrete," International Journal of Engineering Research & Technology (IJERT), Vol. 12, Issue 2, Feb 2023,
2. Anand Parkash and Pardeep Kumar Yadav, "An experimental study on cement concrete with eggshell powder," International Journal of Engineering Research & Technology (IJERT), Vol. 12, Issue 6, June 2023.
3. Yasmeena Javed, Md. Raqeeb, and Sandeep Singh, "Partial replacement of cement with eggshell powder in concrete," International Journal of Civil Engineering and Technology (IJCIET), Vol. 11, Issue 4, April 2020.
4. S. Noormohammad and V. Pavankumar Reddy, "Experimental study on partial replacement of cement with eggshell powder and silica fume in concrete," International Journal of Advanced Research in Science, Communication and Technology, Vol. 20, March 2024.
5. Palli Praveen Kumar and R. Srinivas, "Experimental study on micro silica as partial replacement of cement in M20 concrete," International Journal of Engineering Research & Technology (IJERT), Vol. 7, Issue 11, Nov 2018.
6. Rohit Sharma, "Effect of silica fume on strength and durability of M20 concrete," International Journal of Research in Engineering and Technology (IJRET), Vol. 7, Issue 6, June 2018.
7. Abhilasha G.T., R. Akshay, and P. Kumar, "Effect of GGBS on strength properties of M20 concrete," International Research Journal of Engineering and Technology (IRJET), Vol. 5, Issue 8, Aug 2018.
8. Protima Sarker, M. Alam, and K. Sultana, "Recovery of phosphorus from wastewater using calcined eggshells," Journal of Environmental Management, Vol. 354, Jan 2025.
9. Sahoo, A.., S. Agarwal, and D. M. Pandey. “A REVIEW STUDY ON REPLACEMENT OF CEMENT BY SILICA FUME AND EGG SHELL IN CONCRETE”. International Journal of Technical Innovation in Modern Engineering & Science, vol. 5, no. 5, May 2019, pp. 987-91